The Dollar Exchange Rate, Adjustment to PPP, and the Interest Rate Differential

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Abstract:
We find that the real dollar exchange rate during the post Bretton Woods era is well described by a Markov switching error correction model with PPP as long run equilibrium. There is one mean reversion regime where PPP and the interest parity condition are valid. Contrary, the second, bubble regime is characterized by persistent mean aversion, where the bursting of a bubble does not become more probable with increasing distance from PPP. The unconditional half-life of shocks is about 1.5 years.

JEL-Classification: F 31
Keywords: Real exchange rate modeling, purchasing power parity, PPP, interest rate differentials, Markov switching model, error correction model, dollar

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1 Introduction

Recent research regards the purchasing power parity (PPP) – again – as a valid concept in the longer run (Taylor and Taylor, 2004). An important element in the renaissance of PPP has been the robust finding of non-linearities in real exchange rates (e.g. Sarno and Taylor 1998, Sarantis 1999). The most often referred source of non-linearity in the real exchange rate are frictions in the goods market in terms of segmented markets, transaction and trading costs. Equilibrium models incorporating these issues indicate that the exchange rate is at the same time mean-reverting and non-linear (Dumas, 1992). There is a close relationship between the deviation from PPP and the adjustment speed: As long as the exchange rate is close to PPP the process is divergent with no tendency to return to PPP and therefore the exchange rate will spend most of the time close, but unrelated to PPP. However, if it moves away from PPP trade will take place and force the exchange rate back to PPP, i.e. an adjustment process is started. However, this view of real exchange rate behavior may be too optimistic when we remember the history of the most traded rate, Deutsche mark versus US dollar, which motivated to apply bubble models on exchange rates (see for instance Meese, 1986).

There is another, alternative explanation of non-linearities in the real exchange rate, directly linking goods markets and financial markets (Taylor, 2005). In a model with heterogeneous agents, namely fundamentalists, chartists and noise traders, decisions of goods traders will depend on the advice of financial markets experts. As long as there is no strong consensus among the fundamentalists, the traders will rely more on the advice of chartists, who use trend-following forecasts of the exchange rate (Taylor, 2005). This behavior will lead to different characteristics of the real exchange rate: There may be some kind of cyclic trend behavior in the real exchange rate, which is not necessarily related to the degree of deviation from PPP. Disagreement among fundamentalists may also stem from other fundamentals which seem at the moment more appealing, more urgent to fundamentalists, for instance high interest rate differentials. The heterogeneity of market participants is also stressed by De Grauwe et al. (1993), who use an extended version of the Dornbusch sticky-price model with chartists and fundamentalists, and Brock and Hommes (1996), pointing at the heterogeneity of expectation formation, where the 'winning' forecast approach (or trading rule) of a profitability contest attracts agents. Particularly the latter considerations on frictions in financial markets seem to hint at a cyclical behavior rather than at a threshold model.

Furthermore, surveys among FX dealers and fund managers (e.g. Menkhoff, 1998) show that the majority dealers are of the opinion that the importance of fundamentals varies with the "most urgent problem" (85%) respectively "fashions" (75%).

Whereas the first motivation for non-linearities (frictions in the goods markets) has drawn much attention during the recent years (inter alia Michael, Nobay and Peel, 1997; Obstfeld and Taylor, 1997; Taylor, Peel and Sarno, 2001; Kilian and Taylor, 2003) there have been only recently attempts to introduce non-linearites of the second type to the real exchange rate (Sarantis 1999, Taylor, 2004, Kanas and Genius 2005, Kanas 2006) and hardly any work which consider both sources of non-linearity in the same approach. One exception is Copeland and Heravi (2006), who allow for a single structural break in a smooth transition autoregressive model for several exchange rates. They do, however, focus more on singular macroeconomic events than on cyclical behaviour stemming from frictions in financial markets.

Unfortunately testing between these two kinds of non-linearity is rather difficult, although a number of tests of non-linear cointegrating processes against random walk alternatives have been proposed, no test of Markov switching cointegration against threshold cointegration is available. It is, however, known that available tests for threshold cointegration do have low power and, furthermore, may even have lower power if the true data generating process is an ESTAR threshold process than if it is a Markov switching process, i.e. if the alternative is misspecified (Kruse et al. 2007). The result of such threshold tests therefore cannot guide the researcher to the correct specification.

Our approach is to model real exchange rates in a way that both alternatives – mean reversion as well as bubbles or cyclical trends – may principally occur. Evidence will then reveal whether and to which degree stabilizing arbitrage and destabilizing bubbles are at work. Our use of a Markov switching error correction model does indeed show that both forces play a role and that in particular real exchange rate bubbles are identified.

The intuition of our modeling approach rests on four steps: first, there is the requirement to combine a kind of long run equilibrium, i.e. the PPP, with complex shorter term dynamics which leads to employing an error correction model. Second, it is necessary to go beyond a simple error correction model – which implicitly assumes that there is always the same adjustment process at work – if one is interested to allow for different processes. As Markov switching regimes have shown to be useful in exchange rate modeling (see e.g. Engel and Hamilton, 1990, Engel, 1994, Sarno, Valente and Wohar, 2004, Frömmel, MacDonald and Menkhoff 2005) we introduce them to distinguish between different adjustment processes towards

PPP.[1] Third, we search for the interest rate differential as the most commonly accepted determinant of the exchange rate originated in financial markets as a short term determinant, in particular when there is no tendency to return to PPP. Fourth, as a final step we are interested whether the adjustment speed towards PPP depends on the distance of the exchange rate from PPP and on the magnitude of the interest rate differential. This is modeled by introducing the distance from PPP and the absolute interest rate differential as parameters determining the bursting of a bubble.

We find that the Markov switching error correction model provides a reasonable description of the single most important real exchange rate over the recent period of flexible exchange rates, i.e. Deutsche-mark (and later Euro) to US dollar from 1973 to 2004. The model is well specified. More interesting for our purpose is the fact that two regimes are clearly distinguished which represent a strong mean reversion process on the one hand and a mean averting, i.e. bubble, process on the other, where the exchange rate is determined by the interest rate differential. Regarding adjustment speed, the unconditional half-life of shocks of one standard deviation is only 18 months. This confirms recent suggestions in the literature that the earlier estimated three to five years half-time is too long (see Taylor and Taylor, 2004). These findings suggest that it may be worthwhile to distinguish two regimes in the dynamic process of real exchange rates, one regime of fast mean reversion and another regime with bubble characteristics.

After describing the model and data in Section 2, we present results in Section 3. Section 4 concludes.

[1] In particular, similar Markov Switching error correction models have been applied by Bessec (2002) who examines switches between PPP and the official central parities of exchange rates within the European Monetary System and by Hall, Psaradakis and Sola (1997) to detect periodically collapsing bubbles in British housing prices.

2 Model and Data

Starting point of the analysis is (see for instance MacDonald, 1999) an equation for relative PPP:

$$e_t = \alpha + p_t - p_t^* + \varepsilon_t \, , \tag{1}$$

where e_t is the log nominal exchange rate, α is a constant, p_t and p_t^* are the log domestic (i.e. the German) and foreign (i.e. the US) price indices. The spot rate of the Deutsche mark (since 1998 calculated from the respective Euro values) versus the US dollar and the consumer price indices of Germany and the US were obtained from the IMF's International Financial Statistics database and cover the period from January 1973 to August 2004. This real dollar exchange rate is seen as constant here, justified by less important Harrod-Balassa-Samuelson effects for the dollar during the recent float (Engel, 1999). All series are monthly data and expressed as natural logarithms.

TABLE 1. Standard unit root tests

	s_t	p_t	p_t^*	ε_t
ADF	-1.964	-2.250	-1.973	-2.297**
ADF (trend and intercept)	-2.188	-0.637	-0.160	
PP	-2.323	-2.426	-2.017	-2.258**
PP (trend and intercept)	-2.392	-0.604	0.013	

ADF: test statistic of the augmented Dickey-Fuller unit root test, PP: test statistic of the Phillips-Perron unit root test, Asterisks refer to level of significance against the null hypothesis of a unit root, *: ten per cent, **: five per cent, ***: one per cent, MacKinnon (1991) critical values.

Standard unit root tests in Table 1 indicate that all series are I(1). As the residuals from equation (1) are stationary, eq (1) can be interpreted as the long run dependence in a cointegration relationship and the exchange rate and price levels seem to be cointegrated. Although this result is in line with the more recent literature on PPP (for surveys see Sarno and Taylor, 2002, Taylor and Taylor, 2004), it should be noted that unit root tests for real exchange rates should be interpreted cautiously (Caporale, Pittis and Sakellis, 2003).

The short term dynamics of the exchange rate can therefore be written using the error correction model (ECM) representation

$$\Delta e_t = a + b \cdot (e_{t-1} - \alpha - p_{t-1} + p^*_{t-1}) + c \cdot \Delta e_{t-1} + u_t . \tag{2}$$

Whereas it is generally assumed in the ECM framework that the adjustment towards the long term equilibrium as given by eq (1) is always present, we assume that the error correction mechanism is discontinuous in time. We do this by applying a Markov switching error correction model, where the speed or the presence of adjustment depends on a non-observable state variable. This Markov switching error correction model has been recently proposed by Psaradakis et al. (2004)[2]. In the Markov switching error correction model the error correction mechanism is only working during particular subperiods, whereas for other periods the adjustment process is 'switched off'. This view corresponds well with the observation that there are large deviations from PPP without any observable adjustment. As Psaradakis et al. (2004) point out, the residuals of the long term (cointegration) relation may be globally stationary, but temporarily non-stationary.

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[2] It was however, already used in Hall et al. 1997. More general versions of the Markov switching model have been mainly used for the nominal exchange rate (see for instance Engel and Hamilton 1990, Dewachter 1997, Frömmel, MacDonald and Menkhoff 2005).

The model, however, is flexible enough to capture just a regime-variant adjustment speed or influence of exogeneous variables. Psaradakis et al. (2004) suggest checking first for global cointegration of the variables. For the real exchange rate this has been done in recent empirical research, confirming that the application of more sophisticated econometric methods gives evidence for a cointegration relation (Cheung and Lai 1993).

Hence, the model emerges to

$$\Delta e_t = a + b_1 \cdot (e_t - \alpha - p_t + p_t^*) + c_1 \cdot \Delta e_{t-1} + u_t \text{, if } s_t=1 \tag{3}$$
$$\Delta e_t = a + b_2 \cdot (e_t - \alpha - p_t + p_t^*) + c_2 \cdot \Delta e_{t-1} + u_t \text{, if } s_t=2$$

with the unobservable variable s_t referred to as the *state* or *regime* of the process at date t. We assume that s_t follows a Markov chain of order one and is characterized by the transition probabilities of switching from state *i* to state *j*.

$$p_{ij} = Pr(s_t = j \mid s_{t-1} = i). \tag{4}$$

As our empirical results in the subsequent section show, two regimes can be distinguished with $b_1 \geq 0$ and $b_2 < 0$. Thus the first regime is a bubble regime, where the real exchange rate moves away from the long term equilibrium from eq (1), and the second regime is a regime of mean reversion towards PPP. We refer to this model as the "basic" model.

It is straightforward to include further exogenous variables to the basic model in eq (2) and a natural candidate is the interest rate differential for a couple of reasons: First, the interest rate parity condition is of similar importance as PPP. Second, recent empirical literature suggests that the interest rate differential plays an important role among fundamentals (Frömmel et al., 2005; Cheung et al. 2005 find some explanatory power of the interest parity model for certain subperiods). Third, this outstanding role of the interest rate is supported by questionnaire evidence (Menkhoff, 1998; Cheung and Chinn 2001).

Equation (3) therefore evolves to

$$\Delta e_t = a + b_1 \cdot (e_t - \alpha - p_t + p_t^*) + c_1 \cdot (i_t - i_t^*) + d_1 \cdot \Delta e_{t-1} + u_t \text{, if } s_t=1 \qquad (5)$$
$$\Delta e_t = a + b_2 \cdot (e_t - \alpha - p_t + p_t^*) + c_2 \cdot (i_t - i_t^*) + d_2 \cdot \Delta e_{t-1} + u_t \text{, if } s_t=2$$

often referred to as the Markov switching ADF regression (Hall et al. 1999).

The transition probabilities in this basic model are – as usually assumed in the literature – constant over time. For assessing the impact of the "most urgent problem" we additionally model the transition probabilities p_{11}, that is the probability of staying in the mean reverting regime as depending on the size of the interest differential, and p_{22}, that is the probability of staying in the bubble regime as depending on the distance e_t-α-p_t-p_t^* to the equilibrium. The rationale behind this approach is that if the exchange rate is in the mean reverting regime and the interest rate differential is high, one would expect that the probability of switching to the bubble regime increases, because PPP is dominated by other fundamentals (Menkhoff 1998). On the other hand, if we are in the interest rate regime, without tendency to return to PPP, and the distance of the real exchange rate to PPP is high, one would expect that the probability of switching to the mean reverting regime increases.

$$p_{11}=cdfn(\pi_{1,1}+\pi_{1,2}\cdot|i_t-i_t^*|)$$
$$p_{22}=cdfn(\pi_{2,1}+\pi_{2,2}\cdot|e_t-\alpha-p_t-p_t^*|) \qquad (6)$$

with cdfn being the cumulative density function of the normal distribution. The model from eq. (5) and (6) is referred to as the "augmented" model. Eq. (6) links the Markov switching ECM, which can be described as a model allowing for exchange rate bubbles, to the most commonly used class of threshold autoregressive models (TAR), where adjustment solely depends on the distance to the equilibrium as used by, for instance, Michael, Nobay and Peel (1997), Taylor, Peel and Sarno (2001) and Chortareas, Kapetanios and Shin (2002). Our model with time-varying transition probabilities therefore allows distinguishing the effects of bubbles in the real exchange rate and threshold effects, whose existence is derived from the working of trade barriers.

The probability of being in state 1 based on all information up to the present date t is given by the *filter probability*, which is obtained directly from the estimation algorithm

$$P(s_t=1 \mid \Phi_t)=P(s_t=1 \mid e_1,..,e_t;\, p_1,..,p_t;\, p_1^*,..,p_t^*), \tag{7}$$

where Φ_t is the set of information, consisting of the series of exchange rates ($e_1,..,e_t$) and domestic and foreign price levels ($p_1,..,p_t$; $p_1^*,..,p_t^*$) up to time t.

As we are looking at the exchange rate behavior from an ex post point of view, it seems to be more appropriate to use the *smoothed probabilities* based on *all* available information

$$P(s_t=1 \mid \Phi_T)=P(s_t=1 \mid e_1,..,e_T;\, p_1,..,p_T;\, p_1^*,..,p_T^*) \tag{8}$$

where now Φ_T is the set of information based on the *whole* series of exchange rates and price levels. The smoothed probabilities have been estimated using the filter algorithm by Kim (see Kim, 1994). If $P(s_t=1 \mid \Phi_T)>0.5$ we refer to the exchange rate as being in the bubble regime on this date, and in the mean reverting regime else.

3 Results

The estimation results for the Markov switching ECM are given in Table 2. For the basic model as well as for the extended one two contrary regimes can be distinguished, the first one being a bubble regime, where the exchange rate moves away from PPP, the second one being a mean reversion regime with adjustment to PPP. The fit of the model is slightly better than for relevant alternatives, (random walk, random walk with drift, and an ECM without Markov switching), see Table 3.[3]

Starting with the basic model, it is noteworthy that the (absolute value) of the error correction coefficient is bigger in the mean reverting regime than in the bubble regime. Furthermore, the (unconditional) probability of being in the mean reversion regime is slightly higher than of being in the bubble regime, for the basic model it is 74.4 per cent.[4] Based on the smoothed probabilities from eq. (6) we can identify 3 bubbles (see Figure 1 and Table 4 for characteristics of the bubbles detected). They are all comparatively long lasting, on average more than two years, see Table 4, and cover the weakness of the dollar in the late 1970's (bubble May 1977 to September 1979), the huge dollar appreciation in the mid-1980's (bubble April 1982 to February 1985) and the dollar appreciation after introduction of the Euro (bubble August 1999 to November 2000).

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[3] However, the Markov switching ECM outperforms the competing models even out-of-sample. As we do not focus on exchange rate forecasts the results are not given here but available from the authors on request. We have also estimated the model over different subsamples and found that the estimates as well as the bubble periods detected remain mainly stable.

[4] Calculated as $(1-p_{22})/(2-p_{11}-p_{22})$, see Hamilton (1994), p. 683. The share of bubble months achieved from our empirical analysis, however, is slightly lower, see Table 4.

TABLE 2. Estimation results of the Markov switching ECM

	Basic model		Augmented model	
	state 1 (mean reversion)	state 2 (bubble)	state 1 (mean reversion)	state 2 (interest rate)
a (constant)	-0.0019 (0.216)	-0.0019 (0.216)	-0.0021 (0.154)	-0.0021 (0.154)
b (error correction)	-0.0385 (0.159)	0.0265 (0.283)	-0.090*** (0.002)	0.0008 (0.397)
c (interest rate)	--	--	0.0085*** (0.002)	-0.0015*** (0.004)
d (lagged exch. rate)	0.3490*** (0.000)	0.1404 (0.331)	-0.0656 (0.373)	0.348*** (0.000)
p_{11}	0.980			
p_{22}		0.942		
$\pi_{1,1}$ [a)]			0.7109 (0.381)	
$\pi_{1,2}$ [a)]			-0.5729 (0.380)	
$\pi_{2,1}$ [a)]				1.5509*** (0.001)
$\pi_{2,2}$ [a)]				-5.7226 (0.102)
Loglikelihood	2.2250		2.2522	

a) The reader should note that $\pi_{i,1}$ and $\pi_{l,2}$ cannot be directly interpreted as probabilities.
b) LR: Likelihood ratio test of the augmented against the basic model.
Significance is given in parentheses. Asterisks refer to level of significance against the null hypothesis of a unit root, *: ten per cent, **: five per cent, ***: one per cent.

TABLE 3. Fit of competing models

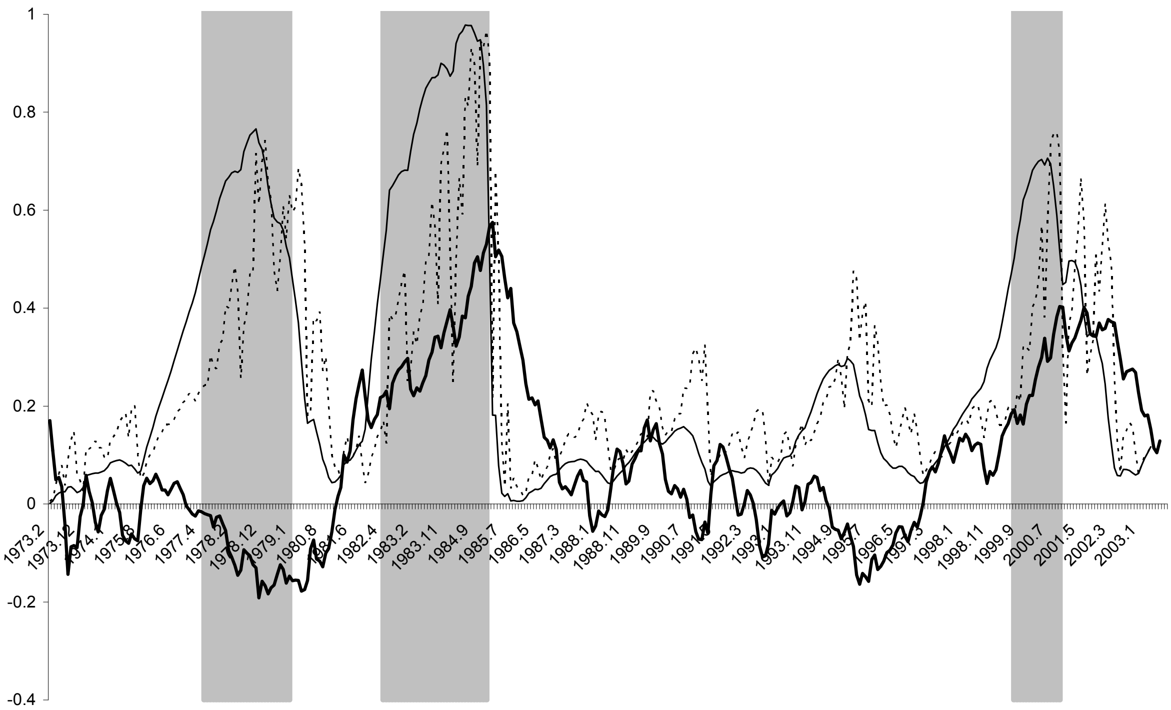
	Basic Markov switch. ECM	Augmented Markov switching ECM	Linear ECM	Random walk	Random walk with drift
MAE	2.0892	2.0676	2.2226	2.2130	2.2235
Relative:	(1.0104)		(1.0846)	(1.0773)	(1.0806)
RMSE	2.6347	2.6180	2.7748	2.7854	2.7815
Relative:	(1.0064)		(1.0660)	(1.0699)	(1.0673)

MAE: Mean average error, RMSE: Root mean squared error, Relative: MAE or RMSE divided by the respective measure of the best model (augmented Markov switching ECM), all values have been multiplied by 100.

The adjustment process of real exchange rates is also characterized by the endurance of any shocks driving the rate away from PPP. The unconditional half-life of a shock, starting from either regime 1 or regime 2 and taking into account possible changes in the regime, is about 1.5 years.[5] This result is quite close to, but still considerably lower, than results for the half-life of shocks to the real exchange rate by studies, which are mainly based on TAR models and lead to estimated half-lifes which are about 3-5 years (Rogoff, 1996). However, our finding of comparatively short half-lifes is supported by more recent studies (Taylor, 2001; Chambers, 2005). For the extended model the results do not differ substantially. Most coefficients show only slight changes. Again, a mean reversion regime with $b_1<0$ and a bubble regime with $b_2 \geq 0$ are identified. At the same time the number of bubbles as well as their average length increases, see Table 4. Figure 2 reveals that the long bubbles from the basic model are also identified by the extended model. The mid-1980's and the 1990's bubble are now identified as longer ones, whereas the end-1970's bubble is shifted to the mid 1970's. Additionally some shorter and less extensive bubbles are identified. The overall picture remains therefore roughly the same as for the basic model. It has, however, to be stated that the exact start and end of a "bubble" may depend on the model used.

[5] This number has been obtained by 1,000,000 simulations of a shock of one standard deviation on a series with the coefficients from our basic model.

FIGURE 1. Real exchange rate and smoothed probability of being in the bubble regime (basic model)

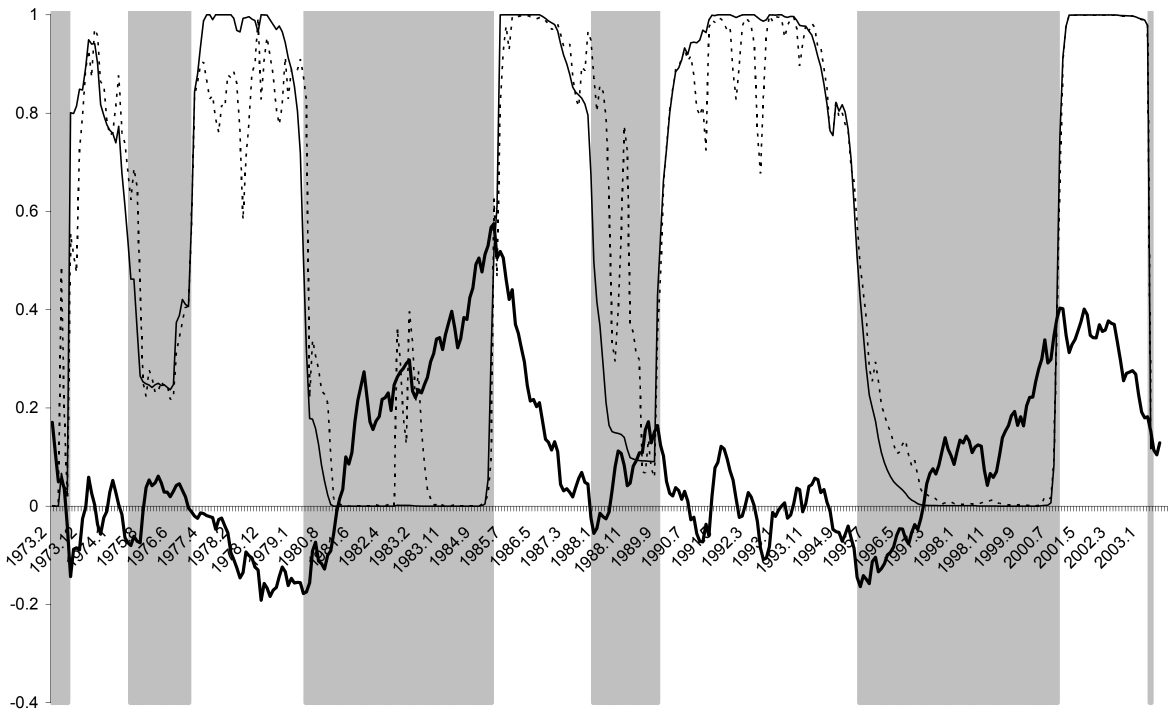


The bold line is the real exchange rate from eq (1), the thin black line is the smoothed probability of being in the bubble regime from eq (7) and the dotted line is the series of filter probabilities from eq (6). The shadowed rectangles represent the periods when the real exchange rate is identified as being in the bubble regime, that is when $P(s_t=1 \mid \Phi_T)>0.5$.

TABLE 4. Characteristics of bubbles

	Basic model	Extended model
Number of bubbles	3	6
≥ 36 months	0	2
24-36 months	2	0
12-24 months	1	2
6-12 months	0	1
< 6 months	0	1
Number of bubble months	80	187
Share of bubble months	22.0 %	51.4 %
Average length of bubbles (in months)	26.7	31.2

FIGURE 2. Real exchange rate and smoothed probability of being in the bubble regime (extended model).



The bold line is the real exchange rate from eq (1). The thin black line is the smoothed probability of being in the bubble regime from eq (7) and the dotted line is the series of filter probabilities from eq (6). The shadowed rectangles represent the periods when the real exchange rate is identified as being in the bubble regime, that is when $P(s_t=1 \mid \Phi_T)>0.5$.

Although the coefficients on the real exchange rate and the interest rate differential are not significant in equation 6, it seems to be informative to take a closer look at the relation between these variables and the regime probabilities. We do this by applying a Tobit regression on the ex ante probabilities:

$$P(s_t=1 \mid \Phi_{t-1}) = \alpha + \beta \cdot [e_{t-1}-\alpha-p_{t-1}-p_{t-1}^*] + \gamma \cdot [i_{t-1}-i_{t-1}^*] \quad (9)$$

This approach may be more effective in finding dependencies as it captures not only the probabilities of changing from one regime to the other, but hints at more global dependencies. The results are given in Table 5.

Indeed, we find a significant interaction between the regime probabilities and the variables under consideration: The positive coefficient on the deviation from PPP indicates that the probability of being in regime 1 (i.e. the regime which is consistent with PPP and interest rate parity) significantly increases with the deviations from the long-term equation. Furthermore, we find the opposite relation for the interest rate differential: The higher it is, the less likely is the regime of adjustment to PPP. The results do not depend on whether we work with the basic or the augmented model and are highly intuitive.

In particular the relation to the interest rate differential seems to be interesting[6]. Figure 3 shows the evolution of the ex-ante regime probability and the interest differential over time. A visual inspection again reveals a strong increase in the interest differential for most periods during which $P(s_t=1 \mid \Phi_{t-1})$ is low, whereas the peaks of the probability are accompanied by low values of $i_{t-1}-i_{t-1}^*$. This relation seems to be even stronger during the second half of our sample. Interestingly, if we work with the absolute interest rate differential, the relation from equation (8) breaks down, indicating that there is an asymmetric relation between the real dollar rate and the interest rate differential: only if the differential is positive, i.e. the rate in the US is the lower one, the probability of being in regime 2 rises.

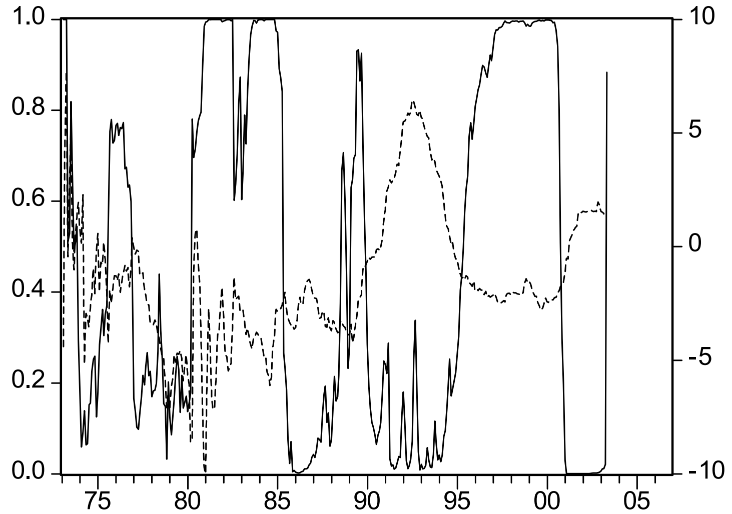
[6] The results do not depend on whether we use the nominal or the real interest rate differential. We do however, use the nominal interest rate differential, as our considerations are based on the behavior of pure financial investors, for whom – if they are located in, say, the Euro area – the US inflation rate is not relevant.

TABLE 5. Tobit model of ex-ante regime-probabilities

dependent variable $P(s_t=1 \mid \Phi_{t-1})$	Basic model	Augmented model
constant	0.203***	0.358***
	(0.000)	(0.000)
Real exchange rate	0.278***	0.275**
	(0.000)	(0.011)
Interest rate differential	-0.017***	-0.057***
	(0.000)	(0.000)

Significance is given in parentheses. Asterisks refer to level of significance, *: ten per cent, **: five per cent, ***: one per cent.

FIGURE 3. Regime probability and interest rate differential



Bold line: the ex-ante probability $P(s_t=1 \mid \Phi_{t-1})$ of the extended model; dotted line: the interest rate differential i_t-i^*_t.

4 Conclusion

The present consensus view of real exchange rate behavior emphasizes their mean reversion properties. Stimulated by research that examines international goods arbitrage as quite powerful, real exchange rate modeling has employed TAR models assuming that adjustment towards PPP becomes stronger with increasing distance from PPP. This paper calls for a somewhat differentiated view: there is mean reversion and it is powerful in the long run but sometimes there may be other forces working stronger in the shorter term dynamics.

These contradictory forces of mean reversion and mean aversion in short term real exchange rate dynamics are considered by introducing a Markov switching approach in the error correction framework of a long run equilibrium model. We find, indeed, that the real dollar rate is characterized by switching regimes of fast mean reversion and of persistent mean aversion, i.e. bubbles. During the stabilizing adjustment process, speed towards PPP is very fast with a half-life of nine months only. Within the destabilizing bubble regime, however, there is no immanent tendency towards PPP, not even with increasing distance of the real exchange rate from PPP.

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